A SEARCH FOR TEV EMISSION FROM UNIDENTIFIED SOURCES IN THE GALACTIC PLANE

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ABSTRACT

The ∼70 unidentified sources of the EGRET sky survey may be one of its most important legacies. The identification of these sources at other wavelengths is critical to understanding their nature. Many have flat spectra out to 10 GeV which, if extrapolated to TeV energies, would be easily detectable relative to the steeply falling diffuse background. The Whipple Observatory γ-ray telescope has been used to observe a number of these which were selected based on their position, intensity and spectrum and in some cases based on a possible association with a supernova remnant or pulsar. No significant emission has been detected from these sources, and upper limits are given.

INTRODUCTION

Despite extensive searches for counterparts to the ∼30 low-lattitude unidentified EGRET sources, the nature of these objects is still largely unknown. Kaaret & Cottam (1996) have suggested that the low latitude unidentified sources show a correlation with OB associations, the sites of massive star formation. Since nearly half of all supernovae occur as the core collapse of young massive stars which explode into star formation regions (e.g., Huang & Thaddeus 1986) a correlation with the positions of pulsars and with supernova remnants also follows. Kaaret & Cottam argue that pulsars emit γ-rays over a significantly longer lifetime than SNR, so that the number of γ-ray pulsars is expected to be significantly larger than the number of γ-ray SNR. However, Esposito et al. (1996), Sturner & Dermer (1994) and Sturner, Dermer and Mattox (1996) have presented evidence for associations of a number of these objects with SNRs (γ-Cygni, IC443, W44, Monoceros) for which there is no pulsar within the 95% confidence error contour (Sturner, Dermer & Mattox 1996). Attempts to detect radio pulsars in the error boxes of EGRET unidentified sources have been unsuccessful (e.g., Nice & Sayer 1997) and provide some constraints on models in which all of the Galactic unidentified sources are pulsars. Since EGRET generally lacks the spatial resolution to distinguish the point-like emission from pulsars and AGNs from the extended emission expected to arise in the vicinity of supernova shells, variability has been used to distinguish compact sources. Dramatic transient sources such as the enigmatic 2CG 135+1 and newly discovered GRO J1838+04 are difficult to interpret as either arising from AGNs or from pulsars, and are possibly representatives of a new class of Galactic γ-ray source distinct from isolated pulsars (e.g., Tavani et al. 1997).

identification of these objects in two important ways. First, the contribution from the diffuse γ-ray background falls as a steeper power of energy ($\sim E^{-2.7}$) than the source spectrum ($\sim E^{-2}$) for many of these objects, implying a smaller effect from uncertainties in the diffuse background model in determining the position, flux and spectra of these sources. Second, the 0.13° angular resolution of the Whipple 10m γ-ray telescope (Lessard and Buckley 1997) provides the ability to resolve extended sources such as SNRs and offers the potential to narrow the error box for bright sources.

OBSERVATIONS AND ANALYSIS

The high-energy γ-ray telescope (Cawley et al. 1990) at the Whipple Observatory employs a 10 m diameter optical reflector to image Čerenkov light from air showers onto an array of 109 fast photomultipliers covering a 3° field of view (FOV). By making use of the distinctive differences in the angular distribution of light and orientation of the shower images a γ-ray signal can be extracted from the large background of hadronic showers.

Data are generally taken in a differential mode where each 28 min ON-source run is followed by a 28 min OFF-source control run which is offset in right ascension to ensure that the same range of azimuth and zenith angles are sampled. While this cancels the zenith angle dependence of the cosmic-ray rate as well as other systematic effects in the camera, differences in sky brightness between the ON-source and OFF-source regions can lead to biases. For some galactic plane sources, such differences are substantial due to either diffuse emission from the galactic plane or bright stars.

Systematic effects arising from such brightness differences can be largely canceled by the procedure of software padding (Cawley et al. 1983). This procedure consists of adding noise to all pixels of each event so that matching PMTs in ON-source and OFF-source runs have identical noise pulse height spectra. Only PMT signals which exceed some multiple of this noise level are included in the subsequent analysis of the shower images (Punch et al. 1993).

The technique used to generate the two-dimensional plots and upper limits is a simple extension of the standard Whipple data analysis (Reynolds et al. 1993) and is described in more detail in Lessard and Buckley (1997). After initial processing of the shower images including pedestal subtraction, gain correction and image cleaning (e.g., Punch et al. 1993) individual Čerenkov shower images are subjected to a moment analysis to determine a set of parameters that characterize the roughly elliptical images. Each point on a two dimensional grid covering the 3° FOV is considered as the potential source position. For each event, the RMS width and length, centroid position, orientation, ellipticity and the skew of the shower image are calculated about this point of origin and tested for consistency with the parameter values expected for a γ-ray event coming from the corresponding direction in the sky. For each grid point the number of candidate events ON-source and OFF-source are calculated, and the significance of the excess, S_λ, is derived using the likelihood ratio method of Li & Ma (1983). In the two-dimensional plots presented in Figures 1, the gray-scale indicates the number of excess counts (candidate γ-rays) consistent with each grid point and the contours shown correspond to the statistic S_λ in steps of 1. Note that due to the large number of trials associated with the 30×30 grid, approximately one S_λ=3 excess is expected for each two-dimensional plot.

While it is desirable to have one control (OFF-source) run for each run ON-source, for some of the data presented here the number of exposures taken OFF-source is less than the number of ON-source runs. In this case, the background level is determined by normalizing the OFF-source data to the ON-source data in a 0.25° band around the perimeter of the field of view. The resulting normalization factor α enters into the calculation of the significance and the upper limit following the procedure of Li and Ma (1983). For the sources J0542+26, J0635+0521, and J1825-1307, little or no OFF-source data was taken and a background template was formed using contemporaneous control data taken for other sources. This results in an additional systematic error for these sources.

In calculating upper limits, we are testing the hypothesis that the emission is coming from a

Table 1: Results of Observations.

Name	Position l	Position b	Nearby Objects	EGRET (> 100 MeV) Flux (10^{-8} cm^{-2}s^{-1})	EGRET Spectral Index	Prediction (> 400GeV) (10^{-11}cm^{-2}s^{-1})	Whipple (> 400 GeV) Exposure (min)	Whipple Flux Limit (10^{-11}cm^{-2}s^{-1})
J0241+6119	135.74	1.22	2CG135+01	87.0±6.7	-2.2±0.1	4.14	972	1.02
J0542+26	181.92	-2.00	S147	17.6±3.5	-3.3±0.5			
J0545+3943	170.79	5.65		12.7±2.8	-3.0±0.3		108	6.72
J0618+2234	189.13	3.19	IC443	45.7±3.8	-1.8±0.1	70.8	1188	0.911
J0635+0521	206.30	-1.20	Monoceros	24.5±4.1	-2.4±0.3	3.09	108	5.59
J0749+17			PSR 0751+1807				486	0.813
J1746-2852	0.17	-0.15	Sgr A*	110.9±9.4			270	0.45†
J1825-1307	18.38	-0.43	PSR B1823-13	84.0±7.9	-2.3±0.1	1.48	702	1.55
J1857+0118	34.80	-0.76	W44 PSR B1853+01	52.1±8.7	-1.9±0.2	29.9	351	2.79
J2020+4026	78.12	2.23	γ-Cygni SNR	122.9±6.8	-2.0±0.1	33.8	513	0.990

† Integral flux above 2.0 TeV.

point source within the EGRET error box. Upper limits calculated for the extended regions corresponding to the IC443, W44 and γ-Cygni SNRs (for 2EG J0618+2234, 2EG J1857+0118, and 2EG J2020+4026 respectively) are reported elsewhere (Buckley et al. 1997). 99.9% confidence-level upper limits are calculated for each grid point lying within the EGRET 95% confidence interval using the method of Helene (1983) and accounting for the declining γ-ray detection efficiency away from the camera center (Lessard & Buckley 1997). The maximum upper limits for each error box are shown in Table 1.

RESULTS AND CONCLUSIONS

Table 1 shows preliminary Whipple upper limits for a number of unidentified sources together with the extrapolated EGRET flux derived from the EGRET spectrum. Fluxes and spectral indices are from Fierro et al. (1996). In addition to sources from the first (Fichtel et al. 1994) or second EGRET catalogs (Thompson et al. 1995), we also include the source J0749+17 from the initial list of unidentified sources by Hartman et al. (1992). This object was not included in the first EGRET catalog because of its low significance ($< 4\sigma$), but is of interest since it prompted the radio pulsar search by Lundgren, Zepka and Cordes (1995) that led to the discovery of the binary millisecond pulsar PSR 0751+1807. Also on our list is the source J0542+26 which was on the list of high confidence unidentified sources in the first but not the second EGRET catalog. This source has a 158 arcmin error radius which could not be shown in Figure 1. This source is of interest since it is coincident with the position of the old, nearby (0.8-1.4kpc, Kundu et al. 1980) SNR S 147 as pointed out by Sturner and Dermer (1994).

These data were taken over the period December 1994 to May 1997. Two-dimensional plots for these sources are shown in Figure 1 excluding results for J0618+2234, J1857+0118 and J2020+4026 which are shown elsewhere (Buckley et al. 1997). Upper limits are at energies above 400 GeV unless otherwise indicated. 2EG 1746-2852 transits at an elevation of $<30^\circ$ resulting in an increase of the effective area and energy threshold by a factor of approximately 5.0 compared with observations at the zenith (Krennrich et al. 1997). While 2EG J1746-2852 shows a small (2.5σ) excess at the position of Sgr A* and within the EGRET error box, this excess is not considered significant given the additional systematic errors present for galactic plane sources. 2EG J0241+6119 shows a similar excess near the position of 2CG135+01 and within the EGRET error box. The excess in J0542+26 lies outside and to the south of the radio shell of S147 and approximately 0.5° away from the X-ray binary 4U0535+262, too far to make an association. The other sources show no significant emission within the EGRET error boxes. Further deep observations with the GRANITE-III high resolution camera should provide better sensitivity given the extended FOV and finer pixelization, and correlations with data taken at other wavelengths should improve chances for detecting variable unidentified sources.

ACKNOWLEDGEMENTS

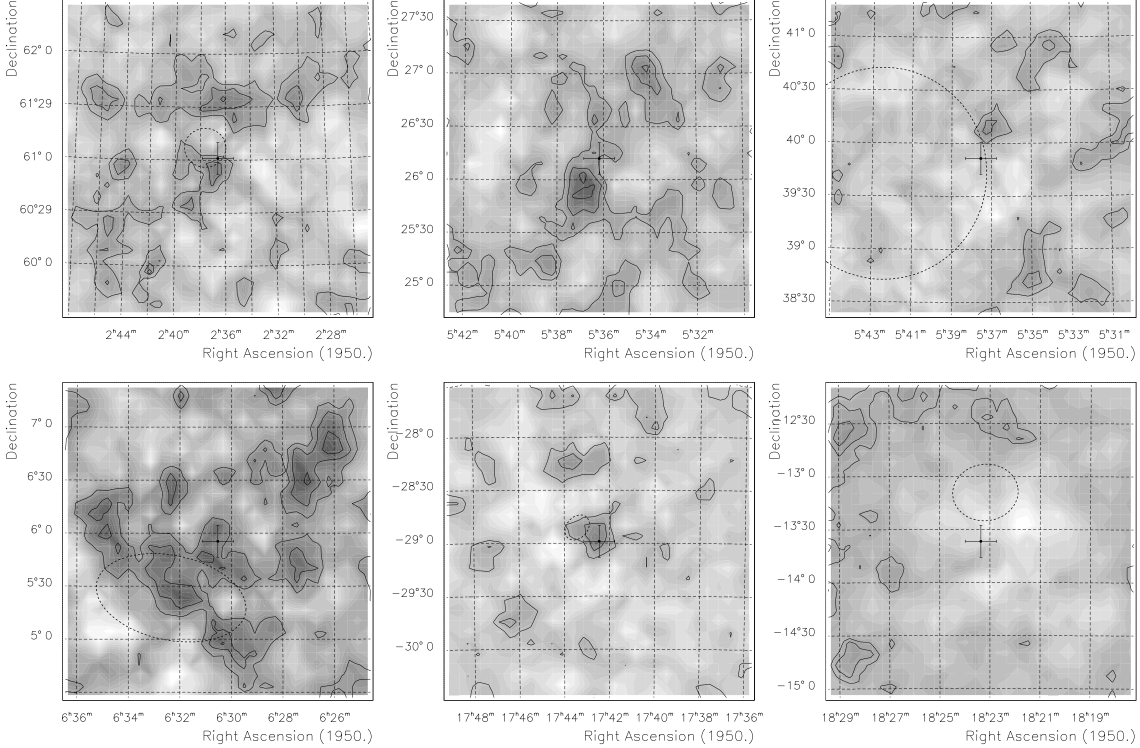

Fig. 1: Plots of two-dimensional distributions of candidate gamma-ray events and contours of S_λ for (a) J0241+6119 (cross at the position of 2CG135+01), (b) J0542+26, (c) J0545+3943, (d) J0635+0521, (e) J1746-2852 (cross at Sgr A) and (f) J1825+2234 (cross at the position of PSR B1823-13). Dotted contours show the elliptical fit to the EGRET 95% confidence intervals. .*

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